

Assessment of maximum aerobic capacity and anaerobic threshold of elite ballet dancers

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Abstract:

An athlete's cardiorespiratory profile, maximal aerobic capacity and anaerobic threshold, is affected by their training regimen and competition demands. The purpose of the present study is to ascertain whether there are company rank differences in maximal aerobic capacity and anaerobic threshold in elite classical ballet dancers. Seventy-four volunteers (M=34, F=40) were recruited from two full-time professional classical ballet companies. All participants completed a continuous incremental treadmill protocol with a 1 km.h⁻¹ speed increase at the end of each 1-minute stage until termination criteria had been achieved (e.g. voluntary cessation, RER <1.15, heart rate ± 5 b.min⁻¹ of estimated HR_{max}). Peak VO₂ (5-breathe smooth) was recorded and anaerobic threshold calculated using ventilatory curve and ventilatory equivalents methods. Statistical analysis reported between-subject effects for gender ($F_{1,67}=35.18$; $p<0.001$) and rank ($F_{1,67}=8.67$; $p<0.001$); post hoc tests reported soloists (39.5 ± 5.15 ml.kg⁻¹.min⁻¹) as having significantly lower VO₂ peak than artists (45.9 ± 5.75 ml.kg⁻¹.min⁻¹, $p<0.001$) and principal dancers (48.07 ± 3.24 ml.kg⁻¹.min⁻¹, $p<0.001$). Significant differences in anaerobic threshold were reported for age ($F_{1,67}=7.68$; $p=0.008$), rank ($F_{1,67}=3.56$; $p=0.034$); post hoc tests reported artists ($75.8 \pm 5.45\%$) having significantly lower %AT than soloists (80.9 ± 5.71 , $p<0.01$) and principals ($84.1 \pm 4.84\%$, $p<0.001$). The observed differences in VO₂ peak and anaerobic threshold between the ranks in ballet companies is probably due to their different rehearsal and performance demands.

Keywords: anaerobic threshold, aerobic capacity, dance

INTRODUCTION

Dance, especially ballet, has been classified as a high intensity intermittent exercise mode[1] similar to soccer and field hockey[2] but unlike its sporting counterparts it has a very high aesthetic skill element. The high skill element of dance training has an effect on limiting its exercise intensity[3] as complex motor skill (e.g. *petite allegro*) cannot be carried out at the same physiological intensity as more simplistic motor skills (e.g. running); this in turn reduces the physiological stimulus for adaptation of the cardiorespiratory system. Previous research has reported aerobic capacity of ballet dancers to be between 39-51 ml.kg.min⁻¹ for female ballet dancers and 50-57 ml.kg.min⁻¹ for males [4-6]. There are a number of possible explanations for the observed variations including when the dancer was tested in the year as Wyon et al [7] reported significant increases in aerobic capacity between rehearsal and performance periods. The protocols and ergometers of these studies varied widely and included the use of treadmills and cycle ergometers, Douglas bags and indirect calorimetry carts, differing lengths of stage time, differing methods of increasing workload which could account for some of the variation in capacities. Rist [8] noted that the artistic demands of ballet performance has increased dramatically in the past 25 years with the introduction of new choreography and an increase in performances a year.

The training and performance environments in sport have a major impact on athletes' cardiorespiratory profiles [9], with supplemental training using relative intensity zones based on the anaerobic and lactate thresholds [10]. This allows specific energy pathways to be developed to enhance performance [11]. Very few studies have examined whether classical ballet places enough stress on dancers cardiorespiratory systems to have a similar effect. Rodrigues-Krause et al [12] monitored isolated ballet exercises in relation to the dancers' first and secondary ventilatory thresholds. They reported that the chosen exercises (*tendús*, *adage*, *rond de jambes*, *fondus* and *jetés*) were all below the higher ventilatory threshold which relates to low to moderate aerobic intensity. The group also looked at cardiorespiratory demands of ballet class and rehearsal but only reported mean data [13], considering both these environs are intermittent in nature more information on work: rest ratios and the accompanying intensities would indicate the energy pathways being utilised. The

limited data on dance rehearsals indicates that intensities increase as they get closer to performance but still remain below the intensities seen during performance [13, 14]. Rimmer et al [15] reported dancers spending significant time in their training heart zones during class and rehearsal suggesting an adaptive cardiorespiratory stress, though other studies have indicated that heart rates remain high during rest periods thereby over-reporting the adaptive periods[14, 16].

A few studies have reported the cardiorespiratory demands of ballet performance, Shantz and Astrand [5] measured excerpts of solo performances using Douglas bags, whilst Cohn et al [17] reported heart rate data. Time motion video analysis has also been used to analyse classical ballet performance using a range of subjective intensity descriptors: very light (slow walk pace with little upper body movement) to very hard (run pace, static holds above shoulder height, multiple jumps and lifts) [18]. Twitchett et al [19] suggests few differences between the company ranks (artist, soloist and principal) in ballet companies in work:rest ratios or the intensity of movement. The observed differences are between the soloist and principal with soloist having significantly more time resting and principals dancing for longer at moderate intensity. Principals also spent longer time at moderate to very hard intensities compared with artists and soloists with less rest periods. These data suggest that principal dancers place greater demand on their aerobic and anaerobic systems (dance sequences 2-5 minutes long), soloists their lactate systems (60-90 seconds) and artists their aerobic system[19]. This reflects previously reported differences in maximal aerobic capacity data of ballet dancers, in which principal and artist dancers had greater capacities than soloists [6], though no differences in anaerobic thresholds were reported. A concern arises when a dancer is promoted to the next rank and they are not prepared for the different physiological demands that the new choreography will place on their body. Therefore understanding the complete cardiorespiratory profile of dancers will allow appropriate supplemental training to be implemented to prepare the dancers for their new roles. The present study hypothesised that there are company rank differences in maximal aerobic capacity and anaerobic threshold in elite classical ballet dancers.

METHOD

Experimental Approach to the Problem

The study utilised an observational cross-sectional design to examine differences in gender and company rank (artist, soloist and principal) for VO₂ peak and anaerobic threshold with age as a co-variant.

Subjects

Seventy-four volunteers were recruited from two full-time professional classical ballet companies in the UK (Table 1), based VO₂max and anaerobic threshold data in the paper by Wyon et al [6] we set alpha at 5% and 90% power giving us a sample size of 10 individuals per group which was achieved with the exception of principal males which had 9 participants. The companies had between 188-225 performances a year and dancers were contracted for 48 weeks a year and 38 hours per week. Prior to dancer recruitment the study received institutional ethical approval. All dancers were free from injury, as determined by their in-house medical teams, and completed a Par-Q and informed consent prior to data collection.

Table 1: Subject demographic data (mean \pm standard deviation) by ballet company rank and gender

	Principal		Soloist		Artist	
	M (n=9)	F (n=10)	M (n=11)	F (n=14)	M (n=14)	F (n=16)
Age (yrs)	32 \pm 4.47	32 \pm 6.09	23 \pm 1.15	25 \pm 2.94	22 \pm 7.61	20 \pm 1.22
Mass (kg)	70.2 \pm 6.33	52.2 \pm 5.12	68.5 \pm 4.45	53.1 \pm 3.29	67.1 \pm 4.42	51.1 \pm 4.77
Height (m)	1.81 \pm 0.06	1.62 \pm 0.07	1.80 \pm 0.12	1.65 \pm 0.09	1.83 \pm 0.44	1.64 \pm 0.51

Procedures

Subjects visited the laboratory twice; on the first visit informed consent was signed, anthropometric data (age, height and body mass) were collected and subjects had a familiarisation period on a treadmill wearing the gas analyser mask. Height was measured to the nearest 0.1cm using a SECA 217 stadiometer and body mass to the nearest 0.5kg with SECA 761 mechanical scales with subjects wearing minimal clothing (leotards and dance tights). The second visit was 1-2 days later; subjects arrived at the laboratory prior to morning class or after a 2 hour rest period to reduce the fatiguing

effects of prior exercise. On arrival body mass collected again and each subject was fitted with a heart rate monitor (HRM (Polar, Finland) prior to a 10 minute warm-up on the treadmill with self-administered stretching if required. The warm-up was used to calculate the speed of the first stage with a target heart rate of approximately $120 \text{ b}\cdot\text{min}^{-1}$. After the indirect calorimetry equipment (3b ultra, Cortex, Germany) was calibrated and the subject fitted with the appropriate mask, 2 minutes resting data were collected with the subject stood on the treadmill. The continuous test started at approximately $6\text{-}8 \text{ km}\cdot\text{h}^{-1}$ as determined by the warm-up. At the end of each 1-minute stage the speed increased by $1 \text{ km}\cdot\text{h}^{-1}$ until the termination criteria were met or the subject stopped the test by stepping off the treadmill. Termination criteria were RER 1.15, heart rate $\pm 5 \text{ b}\cdot\text{min}^{-1}$ of estimated HR_{max} , no increase in oxygen consumption with increase in speed and RPE > 19 [20, 21]. On cessation of the test, gas data were collected for another 1-minute standing before the subject removed the equipment and completed a warm-down.

Data analysis

Single-breathe anomalies, single data points 20% greater than the stage mean, in the expired gas data were removed prior to a 5-breathe smooth. Maximal oxygen consumption is considered to be achieved when there is no increase in oxygen consumption even with an increase in workload [22], only 5 subjects achieved this criteria and therefore VO_2 peak (peak oxygen consumption after 5-breathe smooth) was recorded for all subjects. Expired gas data were analysed using Wasserman methodology to calculate anaerobic threshold [20]. The ventilatory curve method uses the point which there is a non-linear increase in ventilation within the plot $\text{V}'\text{e}$ ($\text{L}\cdot\text{min}^{-1}$) vs time and the ventilatory equivalents method uses the point at which $\text{V}'\text{e}/\text{VO}_2$ increases disproportionately whilst $\text{V}'\text{e}/\text{VCO}_2$ (plotted against time) stays the same or increases slightly [20]. The anaerobic threshold (%AT) was recorded as a percentage of VO_2 peak.

Statistical Analysis

Levene's Tests of Equality of Error Variances and Box's test of equality of covariance were used to test for error variance of the dependent variables across the groups (SPSS v19, IBM). A 2 x 3 (gender

x rank) factorial analysis of variance, with age as a co-variant, was used to examine differences in VO₂ peak and %AT. Scheffe and Tukey HSD were used as post hoc tests to investigate differences between the ranks and eta-squared (η^2) to measure effect size. Significance was set at 5% alpha level for all statistical tests.

RESULTS

The Levene and Box tests indicated no significant difference within the dependent variables; main effects were reported for gender ($F=17.443$; $p<0.001$, $\eta^2=0.342$), rank ($F=11.498$; $p<0.001$, $\eta^2=0.253$) and age ($F=3.752$; $p=0.029$, $\eta^2=0.102$). For VO₂ peak, between-subject effects were reported for gender ($F_{1,67}=35.18$; $p<0.001$, $\eta^2=0.344$) and rank ($F_{1,67}=8.67$; $p<0.001$, $\eta^2=0.206$) with age and gender-rank interaction effects not being significant. Post hoc tests reported soloists as having significantly lower VO₂ peak than artists ($p<0.001$) and principal dancers ($p<0.001$) but not between artists and principals.

Table 2: VO₂ peak and anaerobic threshold data (mean \pm standard deviation) of professional ballet dancers by rank and gender

	Principal		Soloist		Artist	
	M (n=9)	F (n=10)	M (n=11)	F (n=14)	M (n=14)	F (n=16)
VO ₂ peak (ml.kg ⁻¹ .min ⁻¹)	50.5 \pm 1.60*†	45.9 \pm 2.73†	46.1 \pm 2.86*	38.5 \pm 4.64	50.1 \pm 5.22*†	42.9 \pm 3.91†
Anaerobic Threshold (% VO ₂ peak)	83.6 \pm 4.09‡	84.5 \pm 5.60‡	81.5 \pm 6.03‡	80.8 \pm 6.19‡	73.9 \pm 4.66	77.1 \pm 5.74

*Male dancers have significantly higher VO₂ peak than female dancers ($p<0.001$); † Principal and Artist dancers have significantly higher VO₂ peak than Soloist dancers ($p<0.001$); ‡ Principal and Soloist dancers have significantly greater AT than Artist dancers ($p<0.001$)

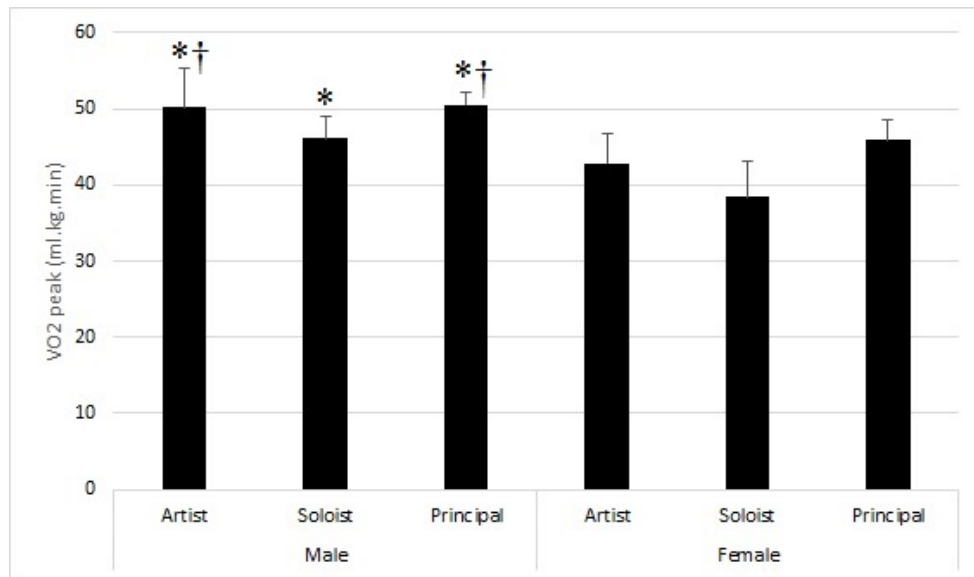
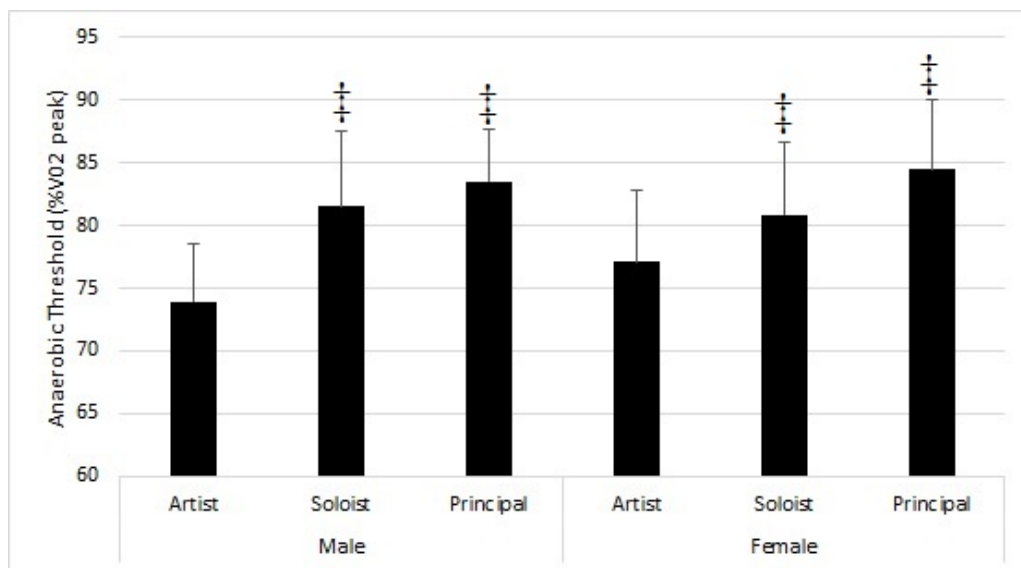


Figure 1: VO₂ peak of professional ballet dancers by rank and gender

*Male dancers have significantly higher VO₂ peak than female dancers ($p < 0.001$);

† Principal and Artist dancers have significantly higher VO₂ peak than Soloist dancers ($p < 0.001$)

Significant between-subjects effects for anaerobic threshold were reported for age ($F_{1,67}=7.68$; $p=0.008$, $\eta^2=0.100$), rank ($F_{1,67}=3.56$; $p=0.034$, $\eta^2=0.096$), but gender and gender-rank interaction effects were not significant. Post hoc tests reported artists having significantly lower %AT than soloists ($p < 0.01$) and principals ($p < 0.001$); there was no significant difference between soloist and p



principals.

Figure 2: Anaerobic threshold of professional ballet dancers by rank and gender

‡ Principal and Soloist dancers have significantly greater AT than Artist dancers ($p < 0.001$)

DISCUSSION

The data from the present study suggests that there are significant differences with medium to large effect sizes in the cardiorespiratory profiles of elite ballet dancers based on company rank, but unlike Wyon et al [6], that noted no significant differences between company ranks, the present study noted for anaerobic thresholds for principal and soloist dancers were significantly greater than the artist rank. In soccer for instance, a player's position could be determined initially by player choice, dominant leg, physical characteristics[23] prior to the player taking on the physiological characteristics of that position[24]. In classical ballet, a dancer's rank within a company is subjectively determined by the artistic director, but to a greater extent is based on skill level, with the entry level and least skilful having the rank of artist, followed by soloists and finally principals who are considered the most skilful dancers in a company [25]. Dance is similar to field sports such as soccer, in that it is intermittent in nature [18, 26] and therefore the work to rest/recovery ratio and the intensity of the work determines the central and peripheral physiological adaptations[27]. Although some types of supplemental fitness training are normal within ballet companies (e.g. Pilates and Gyrotonics), regimens that place an adaptive stress on the cardiovascular and muscular systems (e.g. weight training, cardiovascular training, etc) are beginning to be recognised as an important aspect of dancers' training, but they are still not integrated into their company schedules and therefore needs to be fitted in outside of the dancers' contractual 38-hr working week. The concept of developing specific physical fitness characteristics outside of skills training, as seen within sport, has not developed to the same extent in dance, where physiological development is secondary to skill acquisition. Therefore the different training loads (rehearsals) the company ranks are exposed are a reflection of their roles within a ballet performance which in turn seems to have the greatest influence on their cardiorespiratory profile.

In recent years, sport performance analysis has developed immensely with the use of real-time video analysis and GPS tracking providing coaches and television pundits with immediate feedback [28], in dance post-event subjective video analysis is the only published method of whole dance performance analysis beyond basic reporting of heart rate [17] or gas analysis of performance excerpts [5].

Twitchett et al [19] video analysis of 48 ballet performances reported significant differences in not only the amount of time that different ranks spent dancing on stage but also the intensity of the dance activity. Principals and artists spent the most time dancing during a performance (40% and 47% respectively), though the artists spent the majority of time at light to moderate intensities (approximately 20% of performance time) with 9% of their performance at high intensity. Principal dancers spent 31% of total performance time between moderate and high intensities; this is in stark contrast to soloists who spent only 25% of the performance dancing though this was usually at moderate to high intensity, approximately 17%. Each rank had similar time at very high intensity (4-8%) but as a percentage of their actual dance time, soloists spent the longest period at this intensity. It is recognised that Twitchett et al [19] paper used subjective perceptions of work intensity rather than the more sophisticated methods used in recent studies in different sports [29, 30], but the environment (indoors) and clothing (costumes) often prevent the use of more accurate technologies. Only a few studies have reported indirect calorimetry data for ballet, the early studies measured excerpts from ballet repertoire using Douglas bags [5, 31] or attempted to extrapolate oxygen uptake demands of ballet from heart rate- oxygen dynamics generated from bicycle or treadmill ergometers [15, 17, 32]. The onset of portable gas analysers has allowed greater insight into the physiological demands of ballet [12, 13, 33], but these are restricted to controlled environments and not performance. The video data, that also includes jump and lift frequency, changes in direction, work to rest ratio as well as the previously mentioned dance intensity [18], do provide an insight into the physiological stresses of dance performance. When annual performance frequency is also taken into account (188-225 for the two companies the present participants came from) it is understandable that the cardiorespiratory profile of the dancers is influenced by the dance activity that is linked to their rank in the company.

The cardiorespiratory data in the present study suggest a link between the company ranks with the greatest VO_2 peak (principals and artists) and time dancing during performances as reported by Twitchett et al [19]; principal and artist dancers spent on average 37-47% of the performance dancing whilst soloists just 25%. The anaerobic threshold, expressed as a percentage of VO_2 peak, was higher for principal and soloist dancers in the present study and in Twitchett's study these groups spent a

greater proportion of the dance performances at intensities between moderate to very hard (principal 37% and soloists 28%) compared to artists (22%), who had the lowest AT. The authors recognise that ballet performances are not the only potential influence on cardiorespiratory profiles and that other activities could also have an influence. Presently dance class and rehearsals, which account for the majority of dancers' contracted time, are focused on skill enhancement and choreography and previous studies have noted these training environments do not stress the cardiorespiratory system sufficiently to cause major adaptations [7, 13, 14]. Though a study that monitored daily activity of female ballet dancers, by triaxle accelerometers, reported that soloists had a significantly higher mean workload than the other ranks [3], with soloists and principals spending the greatest amount of time at intensities of 6 METS+ and also had the least amount of rest during the day. The study was limited to female dancers in one classical ballet company and therefore the generalisability is limited though the study does provide an insight into the different daily demands of the ranks beyond data from individual dance classes and rehearsals.

Although dance training is has been reported to be similar to interval training [34] in that there are periods of greater and lower intensities; these periods are not defined by physiological adaptations but by class size, dance sequence and skill level [35]. The possible work to rest ratio (equal rest to exercise ratio during performance) reported by Twitchett [19] has been shown to emphasise development of the aerobic pathways [36]. Therefore applying training theory from sport to dance has severe limitations; but some inferences can be made. The reported performance intensities for the artist rank, light to moderate, have been shown to improve aerobic capacity without significantly effecting ventilatory threshold [37]. This could equate to low intensity training, an intensity that doesn't cause lactate to raise above 2mM [11] that has been shown to develop the slow component of VO_2 kinetics.

The soloists were exposed to higher dance intensities (moderate to high intensity) during performance which potentially is around their AT, thereby moving this breakpoint to the right of their cardiorespiratory profile [38]. The longer rest periods during performance and training reported for this rank could explain the lower VO_2 peak [39]. Finally, the principal dancers have the greatest

workload with regards to time on stage, intensity of dance activity and amount of rehearsals [3, 19]. This could explain the higher reported VO₂ peak and AT observed within the present sample with more time spent in their threshold training zone [11].

In conclusion the observed significant differences in VO₂ peak (principal and artist ranks greater than soloists) and AT (principal and soloist ranks greater than artist) between the ranks potentially highlights an area for intervention. As the artist director determines when a dancer moves through the ranks, it would be beneficial for the support team (PTs, ATs, physiologists) to prepare the dancers physiologically for their new role prior to the commencement of rehearsals. Dancers have reported fatigue as the main perceived cause of injury [40] and the reported differences in rehearsal schedules and performance demands between the ranks [3, 19] are enough to illicit a fatigue effect.

Trainers and clinicians need to understand the differences in VO₂ peak and anaerobic threshold between the ranks in ballet companies is probably due to their different rehearsal and performance demands. Supplemental training needs to develop the rank specific cardiorespiratory profiles of dancers to enhance performance and reduce injury incidence. A concern arises when a dancer is promoted to the next rank and they are not prepared for the different physiological demands that the new choreography will place on their body. Communication between the artist director and the support team would allow a supplemental training intervention to be put in place so that the underlying physiological adaptations have occurred prior to the dancer learning the new choreography.

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